

PSYCHOPHYSICS OF KEY-PECK DURATION IN THE PIGEON

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The duration of the pigeon's key peck was differentially reinforced in either a trials or a free-operant procedure. Mean emitted peck duration was a power function of the duration required for food delivery to occur. The exponents of the power function differed considerably from those observed in earlier research involving longer duration responses in pigeons and other species. The coefficients of variation also did not correspond with those of the earlier research on other responses, nor did consideration of the durations actually reinforced resolve the differences. Duration was neither a function of response rate nor of intermittency of reinforcement. Key-peck duration was changed in an orderly way by differential reinforcement. However, it appeared to be more strongly determined by its duration in the absence of differential reinforcement than were longer duration responses.

Key words: temporal psychophysics, key-peck duration, differential reinforcement, base duration, key peck, pigeons

The typical psychophysical production procedure for studying timing in animals involves reinforcement for responses having durations equal to or greater than a criterion value. The uniform finding has been that emitted duration is a power function of required duration ($T = kt^n$), where T is the mean or median emitted duration, t is the time requirement, and k and n are empirically determined constants. This uniformity encompasses such dimensions of behavior as interresponse time, bar-press duration, response latency, and extended response sequences (see Platt, 1979, for a review).

The duration of the particular response that occurs without time requirements—what DeCasper and Zeiler (1977) called the base or natural duration—sets the lower limit on a meaningful time requirement. If reinforcer delivery entails that the duration emitted be less than the base duration, the requirement necessarily makes no contact with ongoing behavior and therefore can have no effects. The available systematic parametric information all derives from responses having duration criteria larger than .4 sec, because the average base durations were always that size or longer. The importance of studying short durations is em-

phasized by psychophysical studies of human reaction time which show that durations less than .5 sec reveal different quantitative relations than do longer ones (Kristofferson, 1976; Woodrow, 1930).

A response that lends itself to the analysis of very short time requirements is the pigeon's key peck. The mean base duration is less than .05 sec, and typically is about .03 sec (Schwartz, 1977a). Differential reinforcement or punishment can change the mean emitted duration, and duration also varies with the nature of the schedule maintaining responding (Schwartz, 1977b; Schwartz & Williams, 1972). These data indicated that key-peck duration is manipulable, but they did not involve a range of criterion durations sufficient to obtain a function. The present experiment provided the necessary parametric analysis.

METHOD

Subjects

Three White Carneaux pigeons were maintained at 80% of their free-feeding weights. Birds 123 and 126 had previous experience with a variety of reinforcement schedules, and Bird 134 was experimentally naive.

Apparatus

The experimental chamber (Lehigh Valley Electronics, Model 121-6) had one response key. A minimum force of .25 N applied over

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Table 1
Sequence of Conditions

| Condition | Bird 123 | | Bird 126 | | Bird 134 | |
|-----------|----------|----------|----------|----------|----------|----------|
| | t (sec) | Sessions | t (sec) | Sessions | t (sec) | Sessions |
| 1 | .0 | 12 | .0 | 12 | .0 | 12 |
| 2 | .01 | 15 | .01 | 15 | .01 | 15 |
| 3 | .02 | 26 | .02 | 26 | .02 | 26 |
| 4 | .03 | 29 | .03 | 29 | .03 | 29 |
| 5 | .04 | 25 | .04 | 34 | .04 | 25 |
| 6 | .06 | 49 | .06 | 40 | .06 | 47 |
| 7 | .08 | 27 | .08 | 31 | .08 | 28 |
| 8 | .10 | 39 | .10 | 38 | .10 | 38 |
| 9 | .12 | 26 | .12 | 26 | .12 | 26 |
| 10 | .14 | 28 | .14 | 28 | .14 | 28 |
| 11 | .16 | 29 | .16 | 31 | .16 | 29 |
| 12 | .18 | 51 | .18 | 51 | .14 | 51 |
| 13 | .13 | 22 | .05 | 25 | .10 | 34 |
| 14 | .11 | 19 | .0 | 27 | .05 | 13 |
| 15 | .07 | 19 | .14 | 18 | .07 | 16 |
| 16 | .05 | 18 | VI yoke | 18 | .11 | 14 |
| 17 | .10 | 24 | VR yoke | 18 | .13 | 22 |
| 18 | .09 | 25 | .14 | 12 | .09 | 19 |
| 19 | .12 | 24 | | | .07 | 19 |
| 20 | .0 | 24 | | | .05 | 18 |
| 21 | .16 | 18 | | | .02 | 23 |
| 22 | VR yoke | 18 | | | .03 | 25 |
| 23 | VI yoke | 18 | | | .12 | 22 |
| 24 | .16 | 12 | | | .0 | 27 |
| 25 | | | | | .14 | 18 |
| 26 | | | | | VR yoke | 18 |
| 27 | | | | | VI yoke | 18 |
| 28 | | | | | .14 | 12 |

an excursion of 6.0 mm operated the micro-switch mounted at the top rear of the key. The key was located behind the 1.0-mm-thick aluminum front panel and was accessible through a 25-mm circular opening centered 17 cm above the floor. A relay mounted behind the panel provided an audible click when the microswitch contacts were closed and a second click when they reopened. The key could be transilluminated by either two red or two blue 1.1-W pilot lamps. A 5-cm-square aperture centered 5 cm above the floor provided access to Purina Pigeon Checkers (the birds' standard diet) during the 4-sec magazine cycles. During feeder cycles the keylights were turned off, and a 1.1-W white lamp illuminated the aperture. Two 1.1-W pilot lamps, one located in each of the upper corners of the front panel, provided continuous general illumination. Continuous white noise masked extraneous sounds.

Solid-state programming equipment (BRS Digibits, series 200) controlled all experimental events and data recording. Response durations were punched on paper tape and also

were monitored on electromechanical counters. Regular calibration with a Tektronix oscilloscope ensured timing accuracy within .001 sec.

Procedure

Each key closure started a clock that accumulated time in .01-sec increments until the key reopened. If the peck duration equaled or exceeded the minimum time requirement (t), key release was followed by food delivery. For Bird 123 the key was red except during feeder cycles, and response durations less than t simply reset the timer. For Birds 126 and 134 each trial began with the red key, and food delivery followed each duration meeting the criterion. Durations shorter than t were followed by a 4-sec period with the blue key. The key became red after each blue period or food delivery. Responses during blue had no programmed consequences.

Each of the five sessions per week lasted for 25 food presentations or for 2 hr, whichever occurred first. The order of conditions and

number of sessions in each appear in Table 1. A condition lasted until the durations met the following stability criterion: the median duration of three successive daily mean durations was calculated, and the condition lasted until three successive medians (encompassing nine consecutive sessions) neither increased nor decreased monotonically for all three birds. After responding was stable, an additional three sessions were conducted in which peck durations were recorded on paper tape. The only difference in the additional sessions was that the punch sometimes interfered with the binary counter circuit used to terminate sessions after 25 food deliveries, so that these last sessions ended after between 24 and 40 food deliveries or after 2 hr. In all cases the last nine sessions met the stability criterion even if it had been met earlier.

Reinforcer density controls. As the time requirement was increased, the density of reinforcement decreased. To determine whether this factor was responsible for the changes in performance independent of the time criteria, two control conditions were derived from the immediately preceding time requirement (.16 sec for Bird 123, .14 sec for Birds 126 and 134). These requirements had been in effect for 18 sessions (Condition 21 for Bird 123, Condition 15 for Bird 126, Condition 25 for Bird 134). One control condition (VR yoke) maintained the number of responses emitted between successive food presentations in each succeeding session under the time requirement. When the appropriate number of responses had occurred, food was delivered. The sequence of number of responses per food presentation was the same in each session as it had been with the time requirement in effect. This was a VR schedule yoked to the timing condition in terms of the number and sequence of responses ending with and without food. Each session lasted until the number of responses equalled that occurring during the differentiation session on which it was based. The second control (VI yoke) maintained the time between successive food presentations in each succeeding session with the time requirement. The first response occurring after the appropriate interval elapsed was followed by food. The result was a VI schedule yoked to the timing condition in terms of successive interfood intervals, but with no time requirement in effect. Each session lasted as long as the differentiation

session on which it was based. Following the two control conditions, the time requirement was reimposed for 12 sessions.

RESULTS

The solid circles of Figure 1 show the mean peck duration over the last three sessions of each time requirement graphed on log-log coordinates. Because repetitions of conditions produced virtually identical results, the last three sessions of each are combined. (The timing conditions preceding and following the two yoked controls are not included, but these also showed the same results as did the earlier exposure to the same time criteria.) The solid lines show the best-fitting power functions excluding the bracketed points, and the exact functions appear above each set of points. In these and all other functions reported, the Pearson product-moment correlation between the obtained points and those predicted by the best-fitting power function ranged between +.94 and +.98. The sharp decrease in peck duration at the longest requirements for Birds 126 and 134 implied loss of control, perhaps because of very low frequencies of food delivery, and the elevated duration at the .01 sec requirement for Bird 123 perhaps occurred because the requirement was too short to effectively alter ongoing performance. Over most of the range, however, mean peck duration increased as the required duration increased.

The open circles of Figure 1 show the standard deviation of peck durations. Changes in standard deviations, like those in the means, could be described by a power function. The best-fitting equations appear below each set of points, with the same requirements excluded as were omitted for the means. The higher exponents for the standard deviations meant that the standard deviations changed to a greater extent than did the means.

The relation between the means and standard deviations is depicted in Figure 2. The coefficient of variation (standard deviation divided by the mean) increased in a generally monotonic manner with each longer time requirement. Variability increased more rapidly than did mean peck duration.

Probability distributions of peck durations appear in Figures 3, 4, and 5. Except for Bird 134 (Figure 5), the distributions became increasingly skewed with longer requirements.

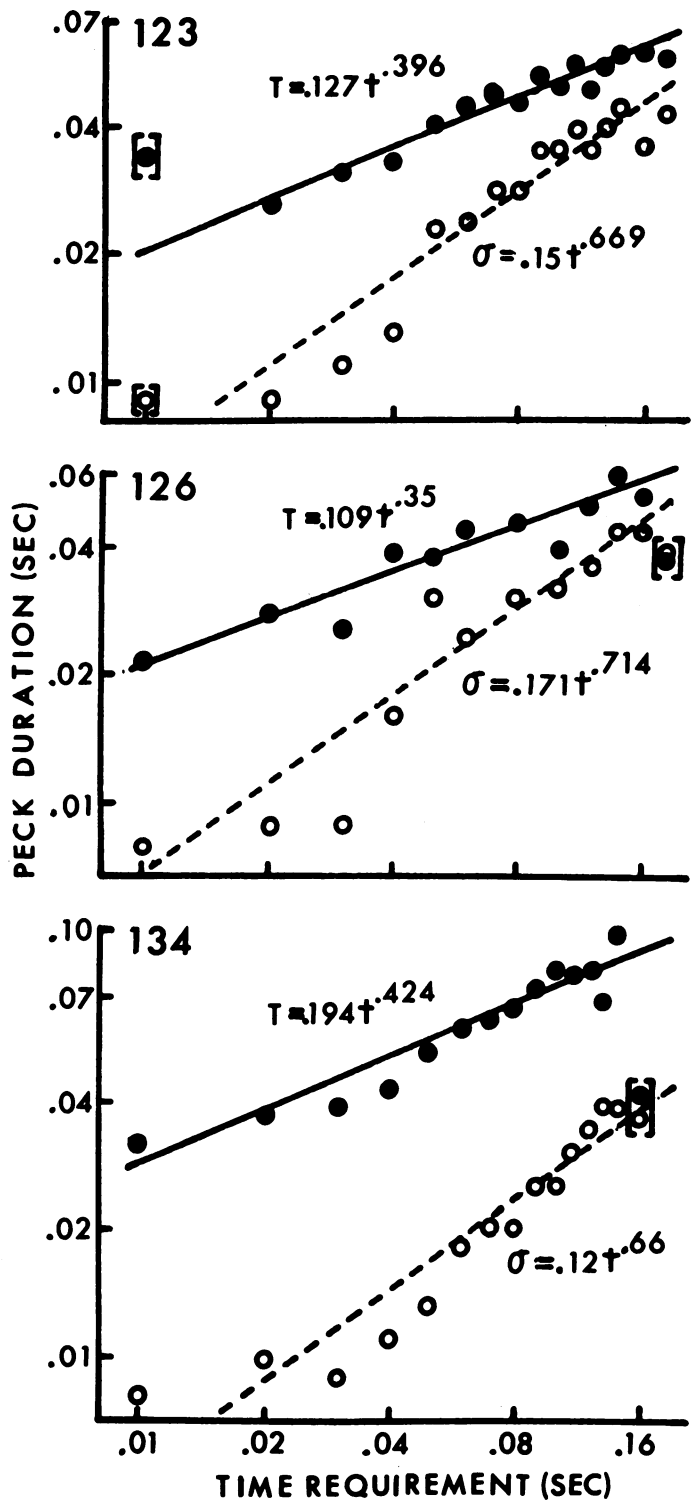


Fig. 1. Mean and standard deviation of peck durations for each time requirement. The best-fitting power function appears adjacent to each set of points. The lines are the curves for these best-fitting functions. Bracketed points were excluded from the functions. Filled circles and solid lines are for the means; open circles and dashed lines are for the standard deviations.

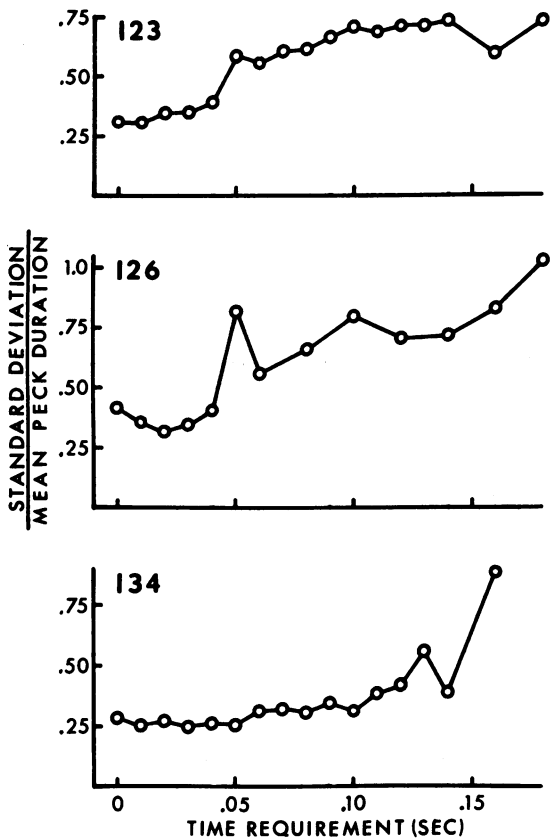


Fig. 2. Coefficients of variation for each time requirement.

Median durations (diagonally hatched bars) did not change to any marked extent for Birds 123 (Figure 3) and 126 (Figure 4), but they did shift for Bird 134. For Bird 123, the overall distributions for requirements between .07 and .13 sec suggested a combination of two component distributions, one centered in the short range of emitted times and the second in the intermediate range. For Birds 123 and 126 the majority of durations remained clustered in the range established without time requirements (0-sec requirement), but for Bird 134 short durations persisted but not with equally pervasive clustering.

Figure 6 (left column) shows mean peck duration as a function of the mean reinforced peck duration, with the best-fitting power function appearing above each set of points. The right column shows the coefficient of variation of the reinforced durations. Mean emitted duration increased along with mean reinforced duration. In general, the coefficient of varia-

tion decreased as mean reinforced duration increased, indicating that variability decreased relative to the mean. The increase in variability of emitted durations (Figure 2) versus the decrease in variability of reinforced durations (Figure 6) derives from the fact that the former considers the entire distribution of durations whereas the latter is truncated by a lower bound established by the reinforcement requirement.

Figure 7 (filled points) shows that response rate either showed a gradual decline over the range of time requirements, or remained fairly stable and then declined with the longest requirements. Reinforcement frequency (open points) decreased as required duration increased.

The yoked-control conditions indicated that the changes in response duration with the time requirements did not stem from the correlated changes in reinforcer density. For Bird 123, the .16-sec requirement produced a mean duration of .06 sec and a standard deviation of .036 sec; the VR yoke yielded a mean duration of .03 sec and a standard deviation of .01 sec, and the VI yoke produced a mean of .029 sec and a standard deviation of .009 sec. For Bird 126, the .14-sec requirement produced a mean duration of .061 sec and a standard deviation of .044 sec; the VR yoke generated a mean of .03 sec and a standard deviation of .009 sec, and the VI yoke produced a mean of .028 sec and a standard deviation of .009 sec. For Bird 134, the .14-sec requirement produced a mean duration of .099 sec and a standard deviation of .038 sec; the VR yoke established a mean of .034 sec and a standard deviation of .009 sec, and the VI yoke produced a mean of .032 sec and a standard deviation of .01 sec. Peck durations in the control conditions resembled those of the shortest time requirements rather than those of the requirements on which they were based. Reimposition of the time requirement in the final condition reinstated the durations characteristic of earlier exposures to the same requirement.

The highest response rates appeared with the VR-yoke conditions (.98, 1.03, and 1.71 responses per sec for Birds 123, 126, and 134 respectively). Rates with the VI-yoke conditions were either lower or about the same as those with the shortest time requirements (.67, .57, and .94 responses per sec for Birds 123, 126, and 134 respectively).

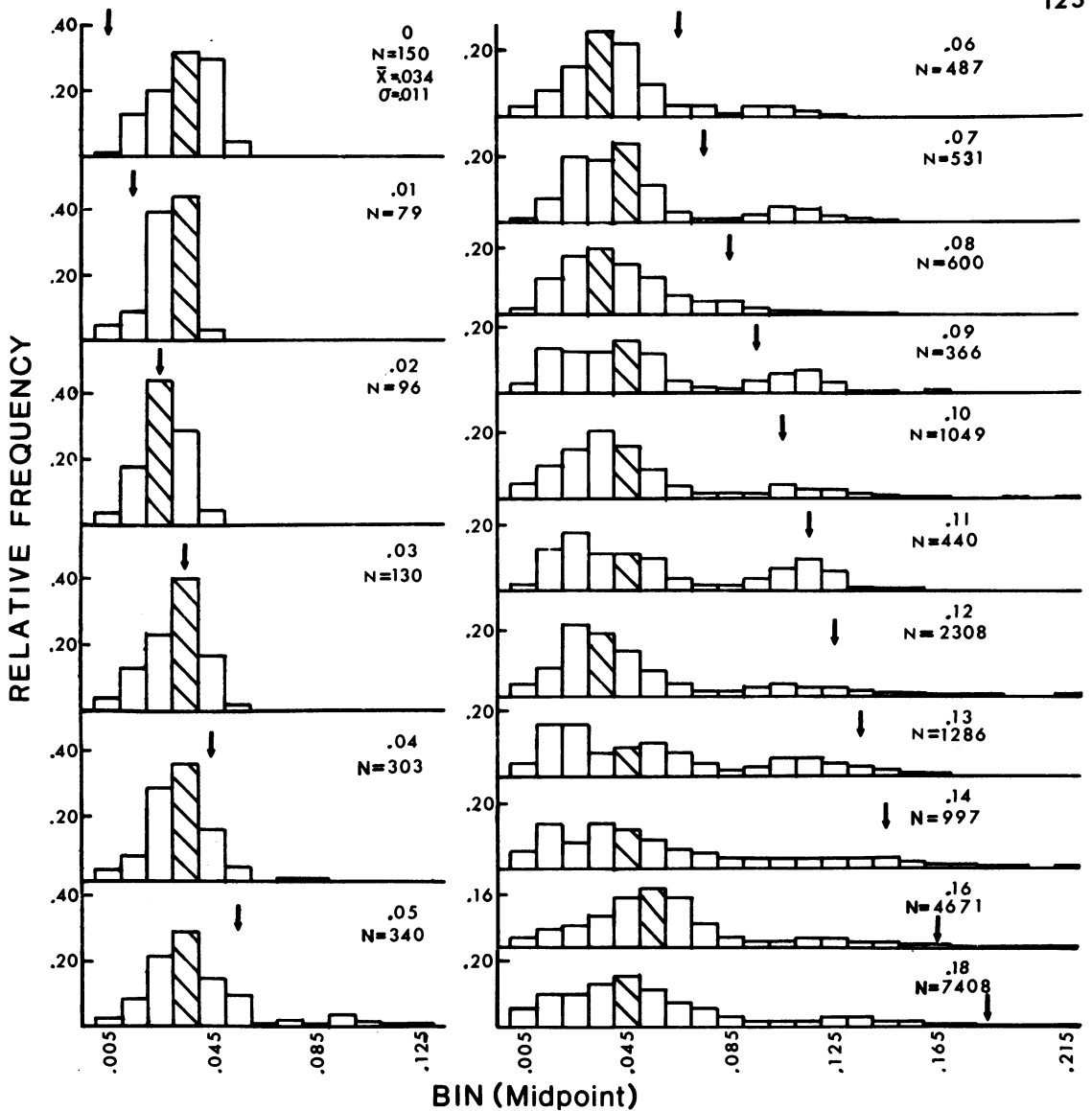


Fig. 3. Relative frequency of occurrence of each duration at each time requirement for Bird 123. The number of durations entering into the distribution, the mean duration, and the standard deviation of durations appear beneath the time requirement. The median duration fell in the bin with the diagonal markings. The arrows indicate the first bin qualifying for reinforcement.

DISCUSSION

Several aspects of the data are relevant to contemporary timing theory: the relation of mean peck duration to required duration, the relation of the standard deviations to the means, and the relation between emitted and reinforced durations. In all of these respects, the very short durations of the pigeon's key

peck differed from longer durations of other responses. In addition, peck duration was not related in an orderly way to response rate.

Mean Peck Duration and Required Duration

The data conformed to previous results in that mean emitted duration (T) could be described as a power function of required dura-

tion in the equation, $T = kt^n$. However, the values of the constants were not close to those obtained in the earlier research. Previously k ranged between 1.1 and 3.3 and n between .57 and .98, but now k fell between .109 and .194 and n between .35 and .424. These discrepancies indicate a quantitative difference between the differentiation of peck duration and other aspects of behavior.

DeCasper and Zeiler (1977) found that bar-press duration in rats, response latency in pigeons, and various aspects of fixed-ratio sequence duration (time from the first opportunity to respond to completion of the ratio, initial pause time, time spent responding) in pigeons were described by an equation having no free parameters. The essential consideration was the base duration (d) of the response in question. Base duration is the time taken

to execute the particular response unit in the absence of a duration requirement. The best-fitting equation was:

$$T = 1.6d^{.18}t^{(.82 - .052 \ln d)}. \quad (1)$$

This equation did not yield predicted values of T even remotely corresponding with the present data. Instead, the best-fitting equation was:

$$T = 5.89d^{1.08}t^{(.96 + .165 \ln d)}. \quad (2)$$

What is most apparent is that d played a considerably larger role in determining peck duration than it did in the differentiation of other types of behavior. The various functions show that peck duration varied in an orderly way with required duration, but the requirement had a smaller effect than with responses having longer base durations.

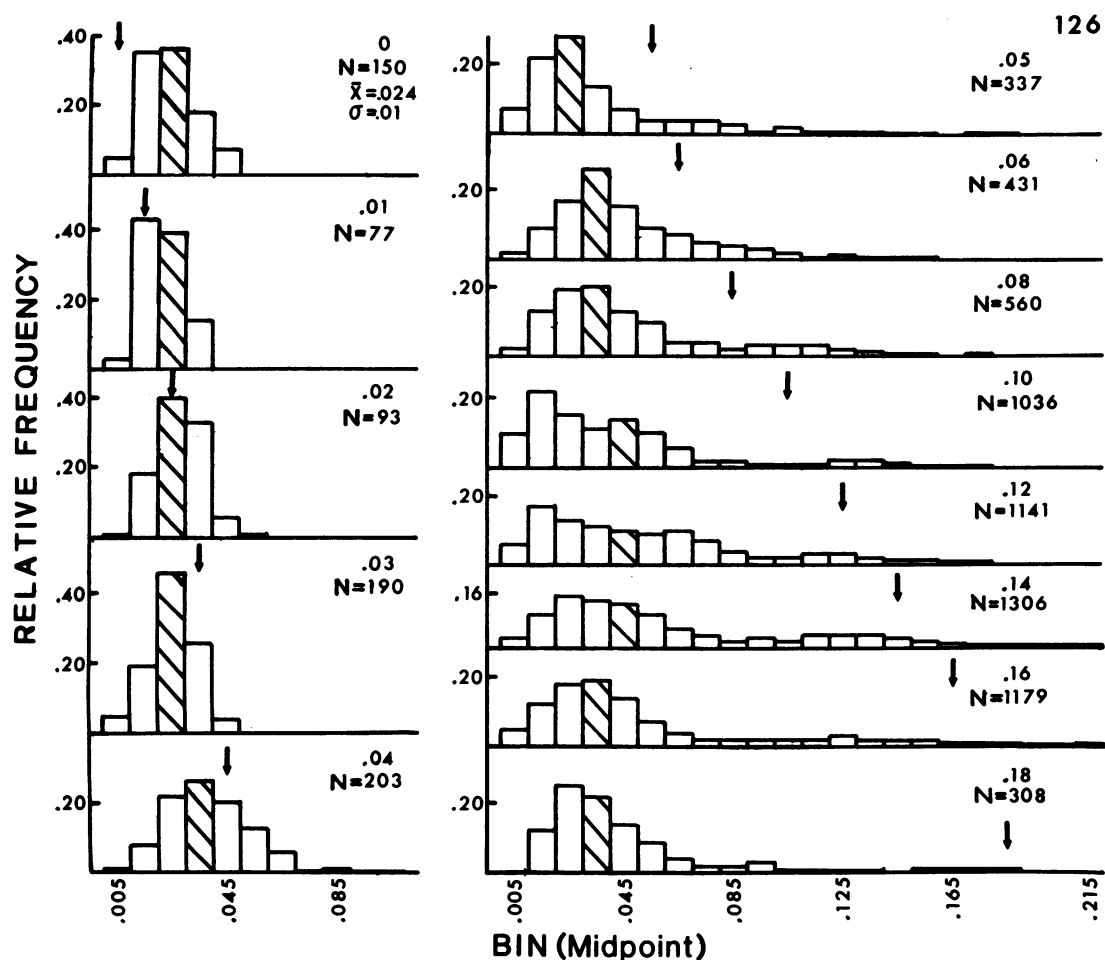


Fig. 4. Relative frequency of occurrence of each duration at each time requirement for Bird 126. Details as in Figure 3.

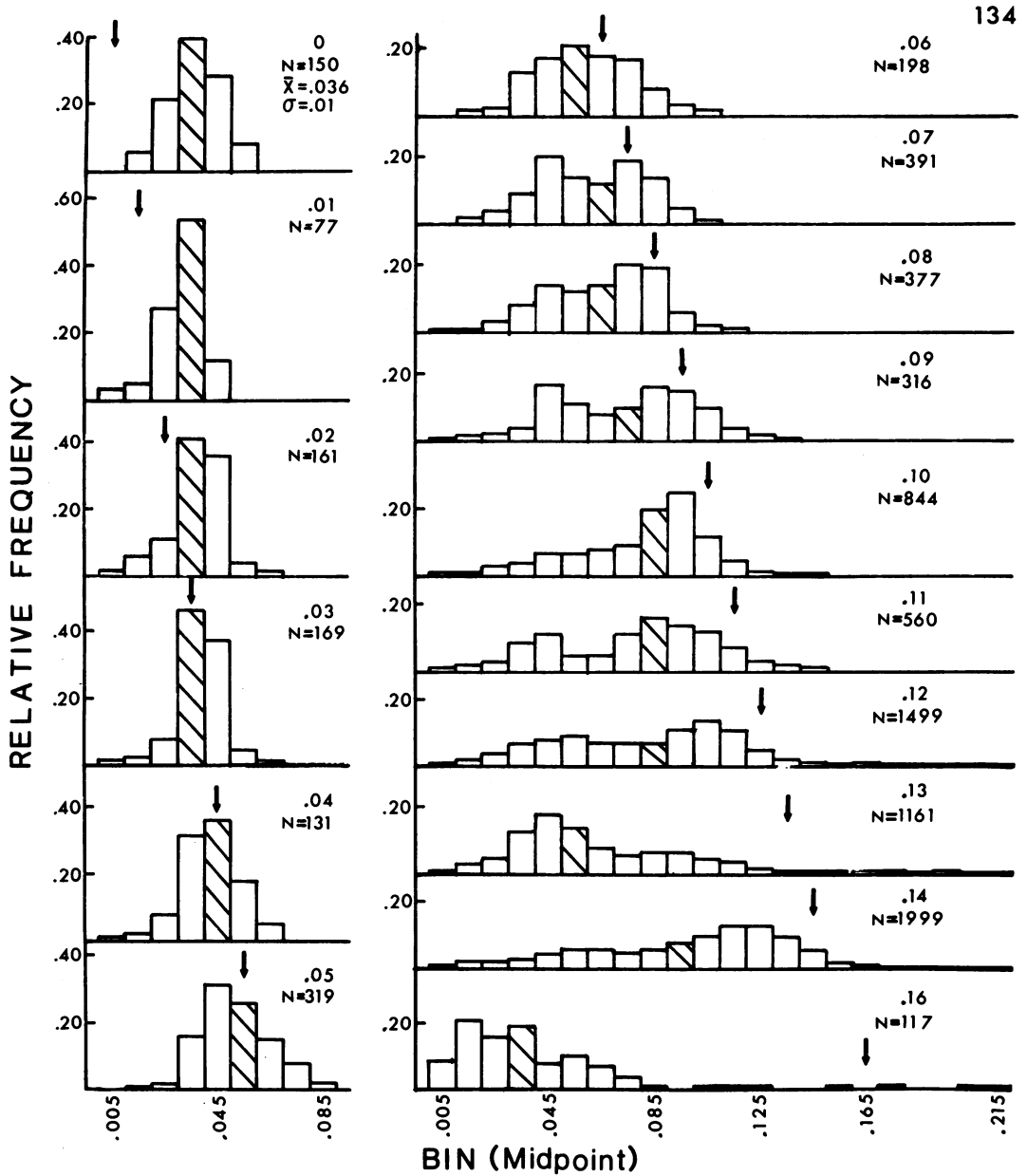


Fig. 5. Relative frequency of occurrence of each duration at each time requirement for Bird 134. Details as in Figure 3.

Mean and Standard Deviation of Peck Durations

Previous studies of temporal differentiation found that the coefficient of variation was constant at about .30 (Catania, 1970; Platt, 1979). This was not the case in the present study. Here, the coefficient increased with suc-

cessively greater time requirements, beginning at about .30 and rising to more than .80.

Other psychophysical investigations of timing have studied durations shorter than those of the differentiation experiments. Woodrow (1930) had adult humans attempt to reproduce time intervals ranging from .2 to 30 sec. The coefficient of variation decreased from

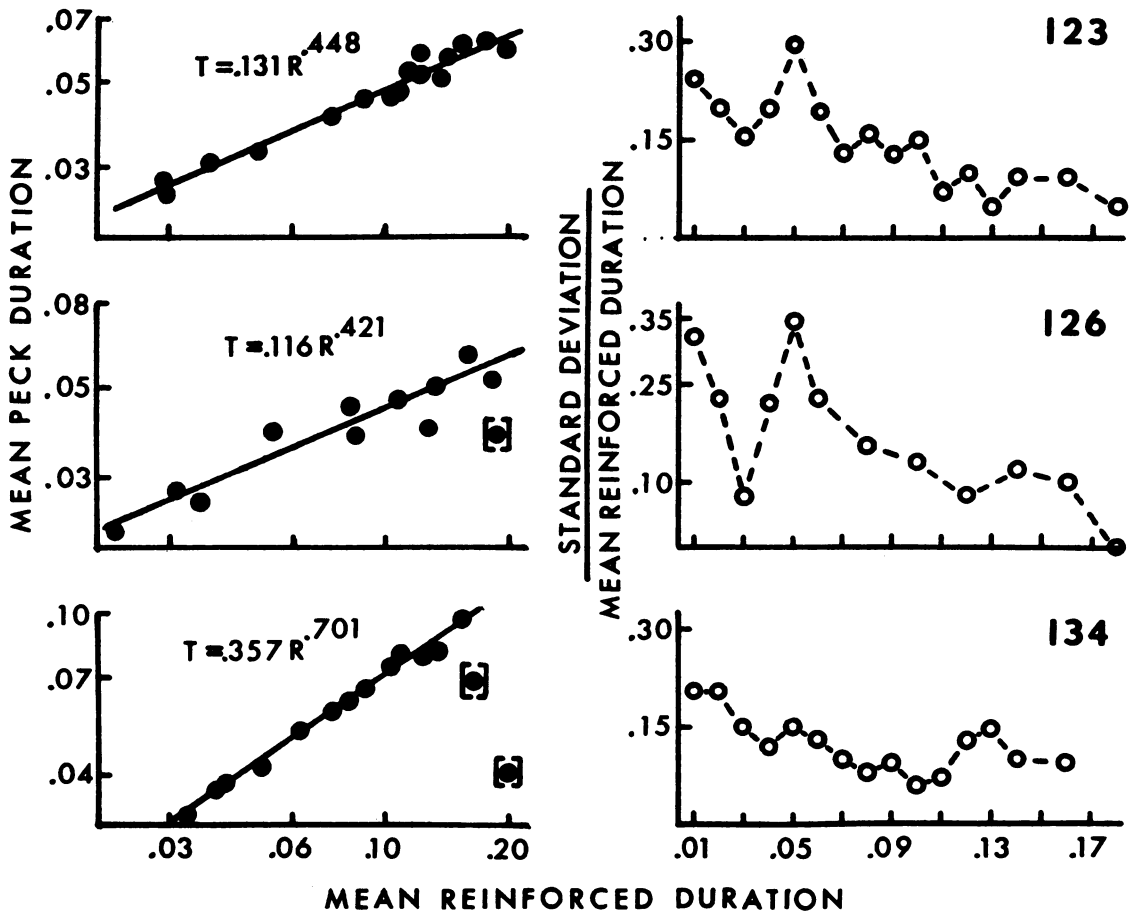


Fig. 6. Mean peck duration as a function of the mean reinforced duration (left column) and standard deviation of reinforced duration divided by the mean reinforced duration (right column). The equations describe the best-fitting power function for the means, and the solid lines depict this function. Bracketed points were excluded from the functions.

.103 at .2 sec to .078 at .6 sec, and then increased to .176 at 30 sec. Kristofferson (1976) instructed humans to produce reaction times ranging from .16 to .93 sec. The curves of the coefficient of variation resembled Woodrow's: they decreased as the mean reaction times increased to .3 sec, stabilized at a lowered value in the .3- to .55-sec range, and then increased again. These data support the conclusion that the coefficient of variation is not constant but instead varies with short time requirements. Gibbon's (1977) contention that timing is scalar is not supported by these observations, because it is the constancy in the coefficient that leads to the idea that the timing process operates in a scalar manner. Apparently, a scalar process does not extend to very short durations.

The present data supplement Woodrow's

and Kristofferson's by extending observations to still shorter durations. As mean duration increased from about .03 to .1 sec, the coefficient of variation also increased. If the various observations are combined (given the hazards in generalizing across species and experimental tasks), it seems that the coefficient first increases (present data), then decreases (Kristofferson, 1976; Woodrow, 1930), and then increases, finally becoming constant with mean durations of 1 sec and longer.

In the present study the standard deviations were more strongly influenced by the time requirements than were the mean durations. These observations imply that a major effect of raising the required duration was to increase variability, with the changes in means reflecting a shift of part of the distribution

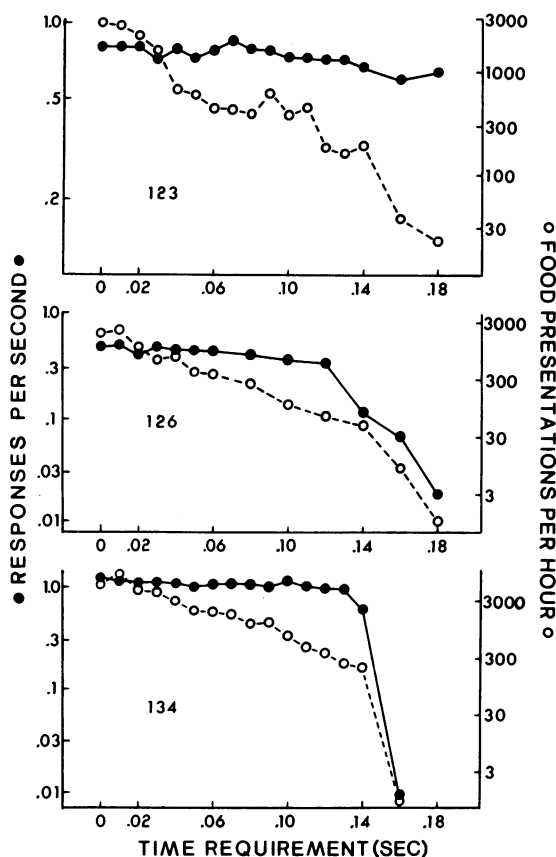


Fig. 7. Mean response rate (filled points) and reinforcements per hour (unfilled points) under each time requirement.

to earlier durations. Sensitivity to time requirements, therefore, seemed to be manifested by increased frequency of long duration pecks combined with the distribution characteristics of the unconstrained base duration.

Emitted and Reinforced Durations

One possible assumption is that it is not the time requirements per se that determined emitted duration but rather the durations that were reinforced. In the present case the requirement would influence behavior by setting the lower bound of the reinforced duration distribution. Gibbon (1977) replotted earlier data and found that the slopes of the power functions relating mean emitted to mean reinforced duration were close to 1.00 for rats and between .76 and .95 for pigeons. He concluded that the relation perhaps was linear with the slopes lowered by autoshaped key

pecks. The slopes in the present experiment were .448, .421, and .701 for the three birds. The deviation from a slope of 1.00 was substantial.

Gibbon (1977) also found that the coefficient of variation of the reinforced distributions was constant. This was not true of the present study. Instead, the coefficients (standard deviation of the reinforced durations divided by the mean reinforced duration) varied, typically decreasing as the mean reinforced duration increased. Once again, therefore, the present short time requirements yielded data differing from those obtained previously with longer durations.

Peck Duration and Response Rate

Their review of the literature led Zirix and Silberberg (1978) to hypothesize that peck duration varies directly with response rate. If rate measures response strength, then it appears that more strongly conditioned pecks have longer durations. The present data do not conform to such a hypothesis: peck duration increased even when response rate and reinforcement frequency decreased. The results of the yoked-control conditions did fit the hypothesis: the VR schedule produced both higher rates and longer durations than did the VI, although the rate differences were considerably more substantial than were the differences in duration. Apparently, the rate-duration relation leading to the suggestion that both are correlates of response strength does not obtain when the reinforcement requirement directly involves response duration and is independent of response rate.

CONCLUSION

The mean duration of the pigeon's key peck can be altered by differential reinforcement, with the relation between emitted and required duration described by a power function. The exponent and intercept of the function differs from those occurring with longer duration responses, as do the coefficients of variation and the relation between emitted and reinforced durations. The data imply that these very short duration responses are more strongly determined by the natural durations occurring in the absence of time criteria than are longer duration responses.

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